• AO88 (Rev. 1/94) Subpoena in a Civil Case

UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF ARIZONA

OPTREX AMERICA, INC.

v.

HONEYWELL INTERNATIONAL INC., et al.

SUBPOENA IN A CIVIL CASE

PENDING IN THE U.S. DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CASE NO. 04-1536 (KAJ)

TO: Karen E. Jachimowicz
4046 W. Carver Road
Laveen, AZ 85339

c/o Matthew Woods, Esq.
Robbins, Kaplan, Miller & Ciresi L.L.P.
2800 LaSalle Plaza
800 LaSalle Avenue
Minneapolis, MN 55402

☐ YOU ARE COMMANDED to appear in the United States District court at the place, date, and time specified below to testify in the above case.

PLACE OF TESTIMONY	COURTROOM DATE AND TIME

☐ YOU ARE COMMANDED to appear at the place, date, and time specified below to testify at the taking of a deposition in the above case.

PLACE OF DEPOSITION	DATE AND TIME

☑ **YOU ARE COMMANDED to produce and permit inspection and copying of the following documents or objects at the place, date, and time specified below (list documents or objects):**

See Attachment A

PLACE	DATE AND TIME
OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C. 1940 Duke Street Alexandria, VA 22314	September 13, 2006, 9:00 am

☐ YOU ARE COMMANDED to permit inspection of the following premises at the date and time specified below.

PREMISES	DATE AND TIME

Any organization not a party to this suit that is subpoenaed for the taking of a deposition shall designate one or more officers, directors, or managing agents, or other persons who consent to testify on its behalf, and may set forth, for each person designated, the matters on which the person will testify. Federal Rules of Civil Procedure, 30(b)(6).

ISSUING OFFICER'S SIGNATURE AND TITLE (INDICATE IF ATTORNEY FOR PLAINTIFF OR DEFENDANT)		DATE
Alexander E. Gasser	Attorney for Plaintiff Optrex America, Inc.	August 14, 2006

ISSUING OFFICER'S NAME, ADDRESS AND PHONE NUMBER:

Alexander E. Gasser, Esq.
OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C.
1940 Duke Street
Alexandria, VA 22314
(703) 413-3000

(See Rule 45, Federal Rules of Civil Procedure, Parts C & D on next page)

PROOF OF SERVICE

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I declare under penalty of perjury under the laws of the United States of America that the foregoing information contained in the Proof of Service is true and correct.

Executed on ______________________ ______________________
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Rule 45, Federal Rules of Civil Procedure, Parts C & D:

(c) PROTECTION OF PERSONS SUBJECT TO SUBPOENAS.

(1) A party or an attorney responsible for the issuance and service of a subpoena shall take reasonable steps to avoid imposing undue burden or expense on a person subject to that subpoena. The court on behalf of which the subpoena was issued shall enforce this duty and impose upon the party or attorney in breach of this duty an appropriate sanction which may include, but is not limited to, lost earnings and reasonable attorney's fee.

(2) (A) A person commanded to produce and permit inspection and copying of designated books, papers, documents or tangible things, or inspection of premises need not appear in person at the place of production or inspection unless commanded to appear for deposition, hearing or trial.

(B) Subject to paragraph (d) (2) of this rule, a person commanded to produce and permit inspection and copying may, within 14 days after service of subpoena or before the time specified for compliance if such time is less than 14 days after service, serve upon the party or attorney designated in the subpoena written objection to inspection or copying of any or all of the designated materials or of the premises. If objection is made, the party serving the subpoena shall not be entitled to inspect and copy materials or inspect the premises except pursuant to an order of the court by which the subpoena was issued. If objection has been made, the party serving the subpoena may, upon notice to the person commanded to produce, move at any time for an order to compel the production. Such an order to comply production shall protect any person who is not a party or an officer of a party from significant expense resulting from the inspection and copying commanded.

(3) (A) On timely motion, the court by which a subpoena was issued shall quash or modify the subpoena if it

(i) fails to allow reasonable time for compliance,
(ii) requires a person who is not a party or an officer of a party to travel to a place more than 100 miles from the place where that person resides, is employed or regularly transacts business in person, except that, subject to the provisions of clause (c) (3) (B) (iii) of this rule, such a person may in order to attend trial be commanded to travel from any such place within the state in which the trial is held, or
(iii) requires disclosure of privileged or other protected matter and no exception or waiver applies, or
(iv) subjects a person to undue burden.

(B) If a subpoena

(i) requires disclosure of a trade secret or other confidential research, development, or commercial information, or
(ii) requires disclosure of an unretained expert's opinion or information not describing specific events or occurrences in dispute and resulting from the expert's study made not at the request of any party, or
(iii) requires a person who is not a party or an officer of a party to incur substantial expense to travel more than 100 miles to attend trial, the court may, to protect a person subject to or affected by the subpoena, quash or modify the subpoena, or, if the party in who behalf the subpoena is issued shows a substantial need for the testimony or material that cannot be otherwise met without undue hardship and assures that the person to whom the subpoena is addressed will be reasonably compensated, the court may order appearance or production only upon specified conditions.

(d) DUTIES IN RESPONDING TO SUBPOENA.

(1) A person responding to a subpoena to produce documents shall produce them as they are kept in the usual course of business or shall organize and label them to correspond with the categories in the demand.

(2) When information subject to a subpoena is withheld on a claim that it is privileged or subject to protection as trial preparation materials, the claim shall be made expressly and shall be supported by a description of the nature of the documents, communications, or things not produced that is sufficient to enable the demanding party to contest the claim.

ATTACHMENT A

DEFINITIONS

1. As used herein, the term "document" shall refer to, without limitation, printed, typed, recorded, photocopied, photographed, graphically or electronically generated, or stored matter, however produced or reproduced, including originals, copies, and drafts thereof, which may be considered a "document" or "tangible thing" within the meaning of Rule 34 of the Federal Rules of Civil Procedure, including but not limited to all patents and all applications, foreign or domestic, as well as correspondence and filings in connection therewith, contracts, agreements, guarantees, amendments, assignments, offers, prospectuses, proxy statements, invoices, purchase orders, research and development records, production records, quality control records, management reports, audit reports, accounting reports, work papers, ledgers, balance sheets, profit and loss statements, financial statements, memoranda, correspondence, communications, computer printouts, computer tapes or disks, envelopes, summaries, analyses, opinions, projections, forecasts, budgets, estimates, transcripts, tape recordings, business cards, notes, calendar or diary entries, newspaper articles advertisements, pamphlets, periodicals, pleadings, indexes, file folders and press releases.

2. As used herein, the terms "Plaintiffs," and/or "Honeywell" shall refer to Honeywell International, Inc. and Honeywell Intellectual Properties Inc., and all divisions, departments, subsidiaries (whether direct or indirect), parents, affiliates, acquisitions, predecessors and entities controlled by any of them, whether domestic or foreign, including but not limited to, Allied Corporation, Bendix Corp., Honeywell Inc., Allied-Signal, and/or AlliedSignal and their respective present or former officers, directors, employees, owners, attorneys and agents, as well as consultants and any other persons acting or purporting to act on behalf of each such entity or person.

3. As used herein, the term "you" or "your" shall refer to Karen E. Jachimowicz individually and/or Karen E. Jachimowicz acting on behalf of Honeywell.

4. As used herein, the term "communication" shall refer to any and all exchanges of information between two or more persons by any medium, including, but not limited to, meetings, telephone conversations, correspondence, memoranda, contracts, agreements, e-mails, computer, radio, telegraph, or verbal actions intended to convey or actually conveying information or data.

5. As used herein, the term "relate" or "relating" shall mean embodying, concerning, containing, comprising, constituting, indicating, referring to, identifying, describing, discussing, involving, supporting, reflecting, evidencing, or otherwise in any way pertaining directly or indirectly to.

INSTRUCTIONS

1. As used herein, the use of the singular form of any word shall include the plural and vice versa.

2. As used herein, the connectives "and" and "or" shall be construed either disjunctively or conjunctively so as to acquire the broadest possible meaning.

3. As used herein, the terms "any," "all" or "each" shall be construed as "any, all and each" inclusively.

4. These requests shall apply to all documents in your possession, custody, or control at the present time or coming into your possession, custody, or control prior to the date of the production. If you know of the existence, past or present, of any documents or things requested below, but is unable to produce such documents or things because they are not presently in your possession, custody, or control, you shall so state and shall identify such documents or things, and the person who has possession, custody, or control of the documents or things.

5. For each and every document for which you assert either attorney-client privilege, work product protection, or some other allegedly applicable privilege, (1) identify the document by date, title, nature, author, sender, recipients, and/or participants; (2) provide a summary statement of the subject matter of the document sufficient in detail to permit a determination of the propriety of your assertion or such privilege or protection; and (3) identify the allegedly applicable privilege or protection.

6. These document requests seek answers current to the date of response, and further shall be deemed to be continuing under Rule 26 (e) of the Federal Rules of Civil Procedure, so that any additional documents referring or relating in any way to these document requests which you acquire or which becomes known to you up to and including the time of trial shall be produced promptly after being so acquired or known by you.

DOCUMENTS AND THINGS TO BE PRODUCED

1. All documents relating or referring to the preparation and prosecution of patent applications that resulted in U.S. Patent No. 5,280,371, listing you, Mr. Richard I. McCartney and Mr. Daniel D. Syroid as inventors, and all related U.S. and foreign patent applications, including invention disclosure documents, prosecution histories, draft applications, prior art, scientific articles or publications, and translations of any such documents.

2. All inventor notebooks or other documents relating to the conception, reduction to practice, research, development, testing, implementation, or analysis of the subject matter described in U.S. Patent No. 5,280,371.

3. All documents relating or referring to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, involving moiré patterns caused by the interaction of cathode ray tubes (CRTs) or liquid crystal displays (LCDs) with other optical elements as seen by the viewer of the image on the CRTs and/or LCDs prior to January 18, 1994.

4. All documents relating or referring to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, involving moiré patterns in active-matrix liquid-crystal light valve (AMLCLV) projection displays and active-matrix liquid-crystal direct-view displays prior to January 18, 1994.

5. All documents relating or referring to the use of multiple lens arrays or other optical elements having different pitches to affect moiré patterns between such optical elements in systems or devices containing cathode ray tubes (CRTs) or liquid crystal displays (LCDs) prior to January 18, 1994.

6. All documents relating or referring to the rotation of one or more lens arrays or other optical elements to affect moiré patterns prior to January 18, 1994.

7. All documents relating or referring to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, involving projection systems using both horizontal and vertical lenticular lens screens prior to January 18, 1994.

8. All documents relating or referring to the need for a Lambertian diffuser as described in U.S. Patent No. 5,280,371.

9. All drafts and versions of the article entitled *Projection Display Technologies* written by you that was published in "Electro-Optical Displays" in August 1992 (attached hereto as Exhibit A), including all prior drafts exchanged with the publisher prior to publication.

10. All documents relating or referring to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, for the Traffic-Alert & Collision Avoidance System (TCAS) program (including, but not limited to TCAS II) prior to January 18, 1994.

11. All documents that refer or relate to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, with Japan Aviation Electronics Ltd. to the extent such work relates to products that include or consist of LCD modules or components thereof, prior to January 18, 1994.

12. All documents that refer or relate to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, with Hosiden Corp. to the extent such work relates to products that include or consist of LCD modules or components thereof, prior to January 18, 1994.

13. All documents that refer or relate to any work performed by you, Mr. Richard I. McCartney or Mr. Daniel D. Syroid, or any other person, on cockpit displays for aircraft, including, but not limited to the F-16, F-22, C-130, or Boeing 777 aircraft, that include or consist of LCD modules or components thereof, prior to January 18, 1994.

14. All documents relating or referring to communications concerning U.S. Patent No. 5,280,371 and/or the application thereof (Serial No. 911, 547).

15. All documents relating or referring to communications or contact with Honeywell regarding C.A. No. 04-1337-KAJ, C.A. No. 04-1338-KAJ, C.A. No. 04-1536-KAJ or C.A. No. 05-874-KAJ, cases pending in the District of Delaware.

16. To the extent the documents or materials in categories 1-15 no longer exist, all documents that evidence the pertinent document retention policies and destruction of these documents.

Exhibit A

ELECTRO-OPTICAL DISPLAYS

EDITED BY
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Marcel Dekker, Inc. New York • Basel • Hong Kong

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About the Series

The series came of age with the publication of our twenty-first volume in 1989. The twenty-first volume was entitled *Laser-Induced Plasmas and Applications* and was a multi-authored work involving some twenty contributors and two editors: as such it represents one end of the spectrum of books that range from single-authored texts to multi-authored volumes. However, the philosophy of the series has remained the same: to discuss topics in optical engineering at the level that will be useful to those working in the field or attempting to design subsystems that are based on optical techniques or that have significant optical subsystems. The concept is not to provide detailed monographs on narrow subject areas but to deal with the material at a level that makes it immediately useful to the practicing scientist and engineer. These are not research monographs, although we expect that workers in optical research will find them extremely valuable.

There is no doubt that optical engineering is now established as an important discipline in its own right. The range of topics that can and should be included continues to grow. In the "About the Series" that I wrote for earlier volumes, I noted that the series covers "the topics that have been part of the rapid expansion of optical engineering." I then followed this with a list of such topics which we have already outgrown. I will not repeat that mistake this time! Since the series now exists, the topics that are appropriate are best exemplified by the titles of the volumes listed in the front of this book. More topics and volumes are forthcoming.

Brian J. Thompson
University of Rochester
Rochester, New York

Contents

6

Projection Display Technologies

Karen E. Jachimowicz*

Honeywell, Inc.,
Phoenix, Arizona

6.1 OVERVIEW

6.1.1 What Is a Projection Display?

A projection display uses projection optics to relay an image, either real or virtual, to the viewer. This chapter discusses those projection systems that create real images viewed with the use of a screen. Virtual image projection displays, which include head-up displays and helmet-mounted displays, are covered in other chapters.

Real image projection displays comprise a light source, an image source, the projection optics, and a screen, as shown in Figure 6.1. The image source and the light source can be one and the same, as in the case of CRT projection displays, or they can be separate, as with light valve systems.

Projection displays are configured with the imaging source in either the front or the rear of the screen. Front projection displays (Fig. 6.2) project the image onto the screen from the viewing side. The screen, which is separate from the projection unit, reflects the image light back into the viewer's eyes. Rear projection displays (Fig. 6.3) project the image onto the back of the screen. The screen can be separate from the projector, as with front projection systems, or the screen and image projector can be included in a single enclosure (a self-contained sys-

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* *Current affiliation:* Motorola, Inc., Tempe, Arizona.

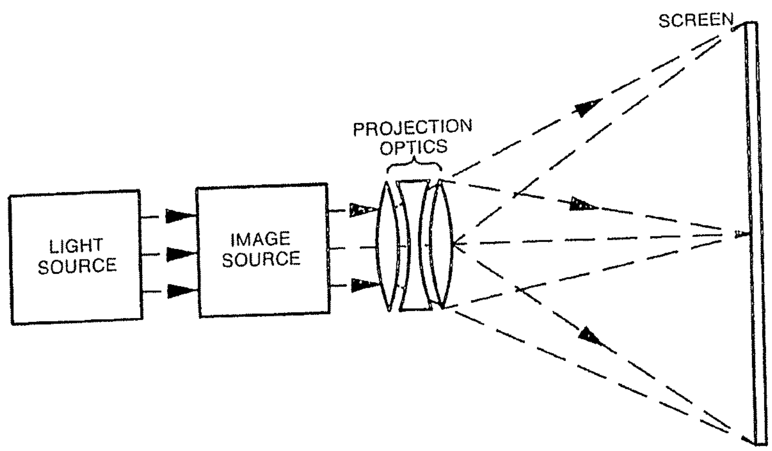


Figure 6.1 Projection display components.

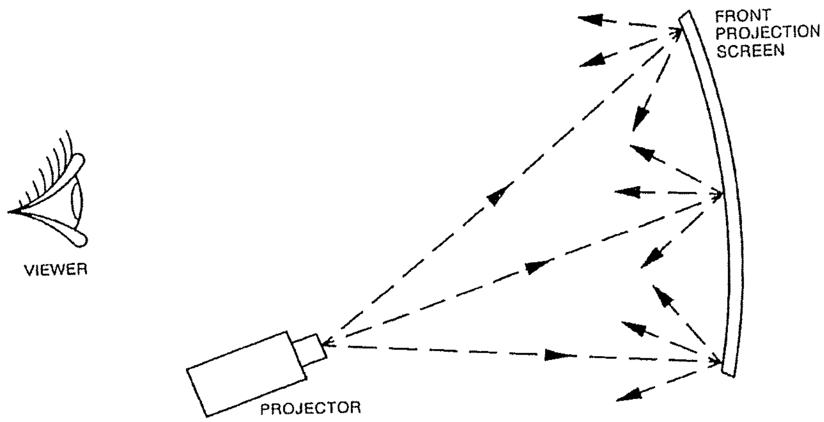


Figure 6.2 Front projection display.

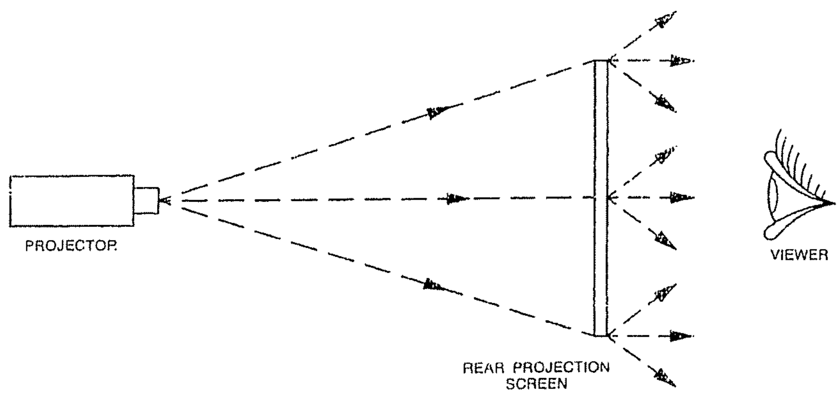


Figure 6.3 Rear projection display.

tem). When the screen and projector are mounted in the same enclosure, the optical path can be folded to create a more compact system. Self-contained systems are less flexible, because screen size or placement cannot be adjusted. In their favor, however, they require less maintenance because operator adjustments for defocus and misalignment are minimal due to the fixed position of the components.

6.1.2 Why Use a Projection Display?

Projections displays are used in applications where the screen is very large or where the screen size is not fixed. Although direct-view displays are getting larger all the time, for screen sizes greater than 30–40 in. diagonally, the practical way to create the image is to generate a small image and project it onto a large screen. Theaters, conference centers, exhibition halls, simulators, education centers, teleconferences, and military command and control centers typically utilize large-screen projection displays.

Projection displays are well suited to applications where the image size is not fixed. A projector with variable focus allows the screen size to be changed to suit the particular situation, unlike direct-view displays, which have a fixed image size.

6.1.3 Characteristics of Projection Displays

Choosing a projection display for a specific application involves reviewing and comparing the capabilities of different projection displays. Display characteris-

tics such as resolution and luminance must be capable of providing the image quality desired. Unfortunately, the techniques used to achieve reported performance characteristics vary widely, so these values cannot be easily compared. The recently published ANSI Standard IT7.215 has been developed to set forth standards for projection display test procedures. This will hopefully result in reported performance data that can be reliably compared. Data comparison is complicated by the fact that the performance of self-enclosed projection displays will include the effects of the screen, whereas the performance of projectors not supplied with a particular screen will not include screen effects. The amount of ambient illumination is critical to performance parameters such as contrast and gray scale, yet a standard environment for taking measurements has not yet been accepted by manufacturers. Consequently, data are taken in varied conditions.

Determining the resolution of a display is therefore not as easy as gathering data from the manufacturer. The information published on displays, including projection displays, is usually the addressability of a system, not its resolution. The information given in this chapter (1) is that reported by the manufacturer, (2) is usually the addressability of the display (a 1280 × 1024 system has an addressability of 1280 × 1024, but if a viewer cannot see this many discrete elements the resolution is a lower value), and (3) should be used for relative comparison very carefully. The issue of resolution and addressability and how to measure them has been handled in depth in display literature (Snyder, 1988; Tannas, 1985), which should be referred to if more information is desired.

It is becoming popular to use the modulation transfer function (MTF) measurement as a measure of display resolution. The MTF is a measure of the image modulation present at a particular spatial frequency of line pairs (one line pair equals one white "on" line and one black "off" line). It is useful to remember that the MTF of a projection display system can be either measured directly at a particular screen or calculated from the MTF measurements of the individual components. Several recent works give the methods for determining the MTF of the different components and the system as a whole (Barten, 1986, 1991; Veron, 1989; Fendley, 1983; Banbury and Whitfield, 1981). The MTF of the display system is the product of the MTFs of the image source, optics, and screen:

$$\mathrm{MTF}_{\text{display}} = \mathrm{MTF}_{\text{image source}} \times \mathrm{MTF}_{\text{optics}} \times \mathrm{MTF}_{\text{screen}} \qquad (6.1)$$

The MTF of the image source is itself a product of its individual component MTFs, such as the MTF of the electronics and the MTF of the phosphor screen if the image source is a CRT. Although the resolution capability of a display system is usually not given in MTF, sometimes it is possible to obtain these values for the individual components. Optics themselves are usually specified in terms of MTF, and it is common to specify the resolution capability of a projection display screen in terms of its MTF.

The luminance of a particular projection display system depends on the flux out of the projection optics and the size and gain of the projection screen used:

$$B_s = \Phi\, G/A \qquad (6.2)$$

where B_s is the screen luminance in foot-lamberts; Φ is the flux out of the projection optics, in lumens; G is the screen gain; and A is the area of the image, in square feet. Gain is actually a function of angle (see Section 6.6), and so the screen luminance is a function of angle also. However, it is common to specify gain and luminance at the on-axis (0°) angle, and therefore the angle dependence is usually left out of the equation.

Luminance values for a self-enclosed projection display will usually be measured at the screen, as the system will always be used with the same screen. A separate unit projector will specify the lumens out of the projection optical system, so the user can then calculate the screen luminance when a screen of a particular size and gain is used.

Reported luminance values are most often obtained when all image sources are full on, which is a situation that rarely occurs in actual use. Luminance can also be specified as peak line luminance, which is a measure of the maximum luminance of a line that is full on, sometimes called "highlight brightness." This is measured by scanning a single "on" line with a photometer, obtaining a luminance profile. The maximum value is the peak line luminance. The numbers given in this chapter are those reported by the manufacturers. Luminance measurement techniques and conventions are available (Csaszar, 1991; Tannas, 1985; RCA, 1974) for obtaining more exact values.

Both monochrome and color projection displays are available. A monochrome projection display uses a single monochrome image source. Most color projection displays use multiple image sources—red, green, and blue—and combine the colors to create a full color image. The color gamut of a particular projection display depends on the chromaticity of the image sources used, which can vary considerably among display types. In order to display a white image, the luminances of the image sources are not equal. The exact mix depends upon the chromaticity of the image sources, but in general, to achieve a standard white the mix is approximately 70% green, 20% red, and 10% blue.

Characteristics such as contrast, modulation, and gray scale are initially determined by the image source itself. The optical system and screen are designed to preserve these characteristics as much as possible. The final characteristics are very dependent upon the situation in which the display is used. The screen affects these characteristics by allowing ambient illumination into the viewing volume. In a situation where there is little ambient illumination, the screen can be designed such that it will preserve the image quality of the image source. As the amount of ambient illumination increases, the final image quality depends

largely on how well the screen minimizes ambient illumination reflected into the viewing volume. Reflected ambient illumination degrades the contrast, modulation, and gray scale of a projected image. This phenomenon is covered in more detail in the section on projection screens (Section 6.6).

Convergence is a measure of how well the three individual images of a color projection display are spatially aligned with each other on the screen. Misconvergence in a projected image can cause a pixel that is supposed to be white seem to be a different color because the red, green, and blue images are not fully superimposed. Misconvergence has several causes, including the individual images not being of the correct geometry, the images not being properly positioned at the screen, or image distortions being introduced by the optical system. An example of misconvergence of images is shown in Figure 6.4.

Different types of projection displays have different sources of convergence errors and different strategies for dealing with them. Some systems require considerable time for converging before they can be used, which is a factor in how well the system will meet the display need. Convergence techniques are covered in more detail in Section 6.7.

Other considerations involved in the choice of a projection display include the physical dimensions of the projector, the power consumption, and the speed of the display. Although most display applications require the system to work in real time, some extremely high resolution projection displays are available, specifically for displaying CAD images or maps, that are not required to operate in real time.

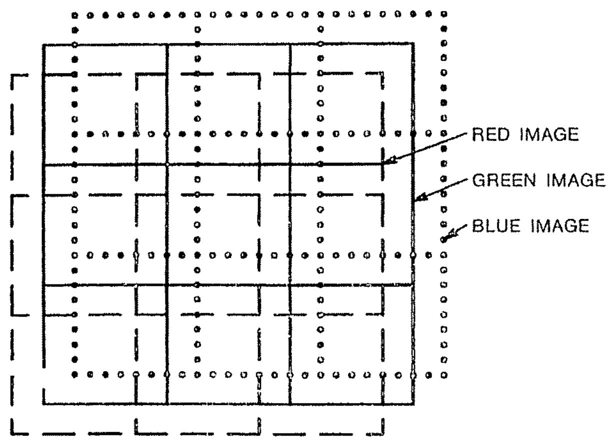


Figure 6.4 An example of misconvergence of projected images. The red, green, and blue images should superimpose one another.

The size, weight, and power consumption of the different systems depend on the particular type of system. Active matrix LCLV video projection displays are probably the smallest color video projectors, with screen sizes as small as 20 in. diagonally. There is almost no practical limit to the maximum size of a projection display. Laser projection displays routinely provide backdrops for concert hall performances and large outdoor crowd shows, which can cover thousands of square feet.

The rest of this chapter provides an overview of the major projection display types, how they operate, and their general characteristics.

6.2 CRT PROJECTION DISPLAYS

The most common type of projection displays in use today are those that use CRTs as the image sources. CRT projection displays provide a high-quality dependable image, relying on mature CRT technology. These systems are very flexible, many being capable of use in either front or rear projection implementations, with multisync capability allowing a wide range of signals to be accepted, and with variable-focus optical systems allowing use with a variety of screen sizes. Consumer CRT projection TVs have proliferated in recent years, illustrating the strengths of CRT projections: high-quality image, low cost, reasonable size, and reliability.

The major drawback of CRT projection displays is the inherent inverse relationship between CRT luminance and CRT resolution. Raising the luminance of a CRT requires more electrons, resulting in a larger electron beam, which lowers the resolution capability of the CRT. Although many new techniques for improving CRT luminance are becoming available and will be discussed, in general to raise both the luminance and resolution of a CRT, the CRT size also must increase.

6.2.1 Operating Principles of CRT Projection Displays

In a CRT projection display, one or more monochrome CRT images are projected onto a viewing screen. By overlaying the red, green, and blue images on the screen, a full color display is formed.

Projection CRTs are very similar to monochrome direct-view CRTs. The basic construction and operation of CRTs are covered in Chapter 1. Flat CRTs are introduced in Chapter 4. Projection CRT differences stem from the fact that projection CRTs must be very bright so the image can be magnified. Projection CRTs are specifically designed to achieve maximum brightness and resolution simultaneously. They are operated at high anode voltages (30–50 kV is com-

mon); use special cathodes such as dispenser cathodes, which provide high electron beam current; and may use liquid-cooled faceplates, as operation at high beam current raises the temperature, which lowers the phosphor efficiency. A typical projection CRT, which operates at 35 kV and several milliamperes of beam current, is shown in Figure 6.5.

CRT projection display optical systems can be either refractive or reflective. The first high-performance CRT projection displays used reflective (Schmidt) optics. Reflective optical systems (Fig. 6.6) can be designed to collect a large portion of the light emitting from a CRT. A high-quality Schmidt system will have a collection efficiency of about 33%, compared to a collection efficiency of 20% for a high-quality *f*/1.0 refractive lens system (Todd and Sherr, 1986). This high performance is achieved in Schmidt optical systems without introducing serious aberrations (Patrick, 1972). Reflective systems are still used, and one system includes the reflective optics within the CRT (Forrester, 1990).

Refractive CRT projection optics (Fig. 6.7) have become the more popular. Their advantages are small size and low weight, especially when plastic optics are used. Refractive optics are also easily implemented into a variable-focus design. The major disadvantage of refractive projection optics is that high collection efficiency is at odds with the requirements for small size, minimum aberra-

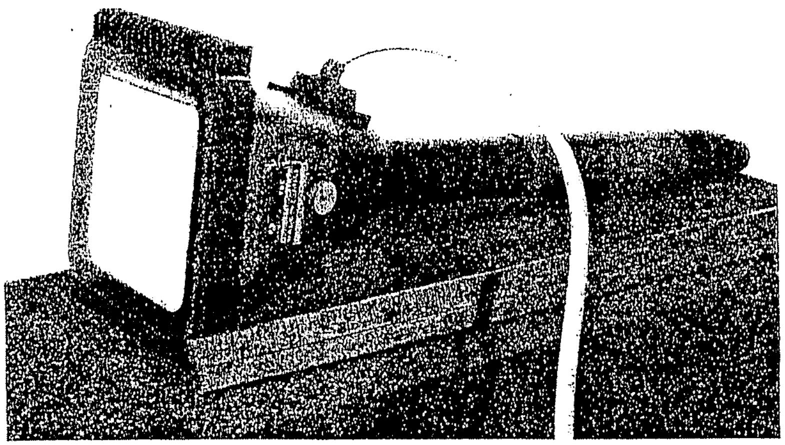


Figure 6.5 A Thomson-CSF projection CRT with a liquid-cooled faceplate.

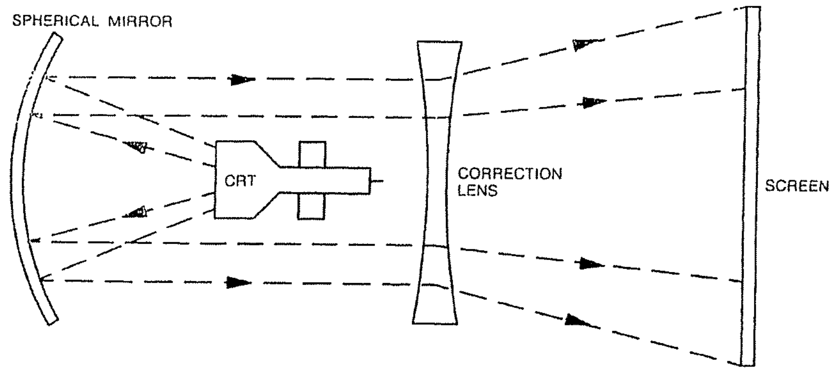


Figure 6.6 CRT projection display with reflective (Schmidt) optical system.

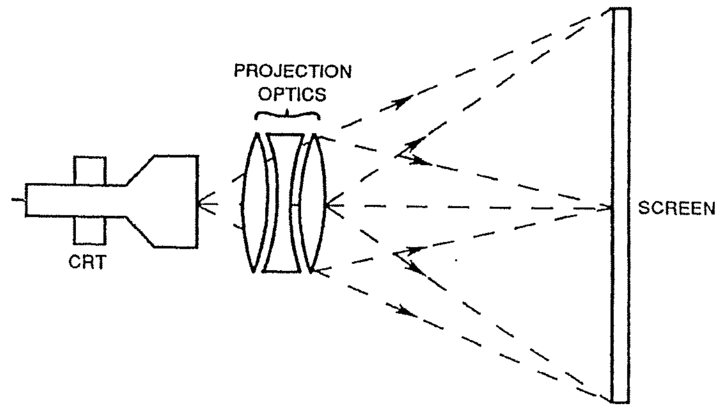


Figure 6.7 CRT projection display with refractive optical system.

tions, and low cost. This trade-off has been mitigated by the increased use of computer optical design programs, aspheric optics, and plastic optics. A large amount of work has gone into optimizing refractive projection optical systems, resulting in high-performance systems becoming available that provide a relatively high collection angle simultaneously with the resolution and costs consistent with the application.

In a color CRT projection display, the images from red, green, and blue monochrome CRTs are combined to create a single full-color image. Image combination is performed using either an off-axis or an on-axis technique. In the off-axis method (Fig. 6.8), the three CRTs direct their images to the screen from different angles, off-axis from each other, and the images are made to superimpose at the screen. The on-axis technique (Fig. 6.9) uses a beam combiner to merge the images before transmission through the projection optics. The three images are then coaxial and form a single full-color image, which is then projected onto the screen.

The advantages of the off-axis system are that packaging is simpler and the optics can be specifically designed for the appropriate color of CRT being used. The off-axis system is the least expensive system and is the most common image-combining technique among CRT projection displays.

Disadvantages of the off-axis technique are the need for trapezoidal distortion correction and the fact that the three images must be reconverged whenever the screen size is changed. Trapezoidal distortions occur because the two outer CRTs

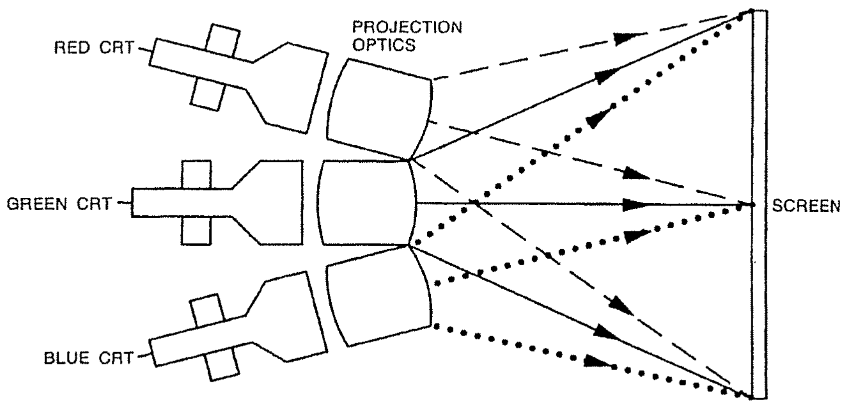


Figure 6.8 Off-axis technique for combining monochrome images in a full color CRT projection display.

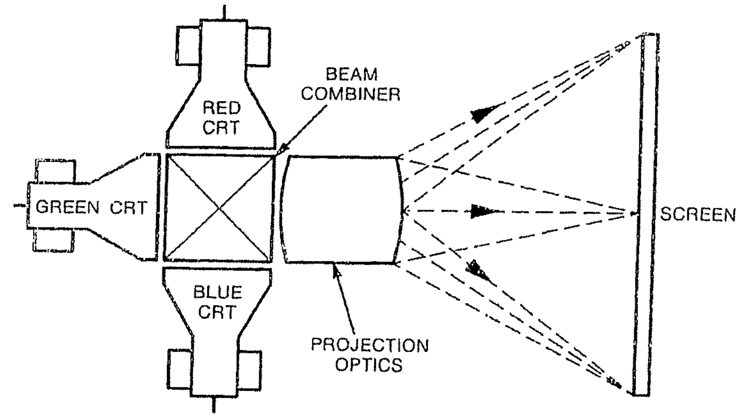


Figure 6.9 On-axis technique for combining monochrome images in a full color CRT projection display.

are at an angle to the screen, creating distortion in the images and resulting in misconvergence at the screen (Fig. 6.10).

Trapezoidal distortion can be corrected optically at the CRT faceplate (Hockenbrock and Rowe, 1982) or by electronically predistorting the image on the CRT so the image will be correct when it reaches the screen. An example of predistorted CRT images for the correction of trapezoidal distortions is shown in Figure 6.11. A particular distortion correction is valid only for one particular throw distance, however. Each time the screen size or placement is changed, the system must be reconverged.

The on-axis optical technique uses a beam combiner to merge the three CRT images before the projection optics. The image is then projected onto the screen with a single set of projection optics. The beam combiner is an optical device that uses dichroic coatings to selectively reflect or transmit the different wavelengths of light, resulting in the images being coaxial. The operation of a cube beam combiner as used in a CRT projection display is shown in Figure 6.12. The beam combiner can be constructed of individual prisms coated and cemented to form a cube or individual coated glass plates. There are a number of beam-combining implementations besides the cube format (Scholl, 1987), but for CRT projection displays the most common technique is the cube beam combiner.

Beam combiners operate such that green is allowed to pass straight through the cube, red is reflected off a dichroic coating designed to reflect red light incident at 45° and pass all other wavelengths (Fig. 6.13), and blue is reflected off a

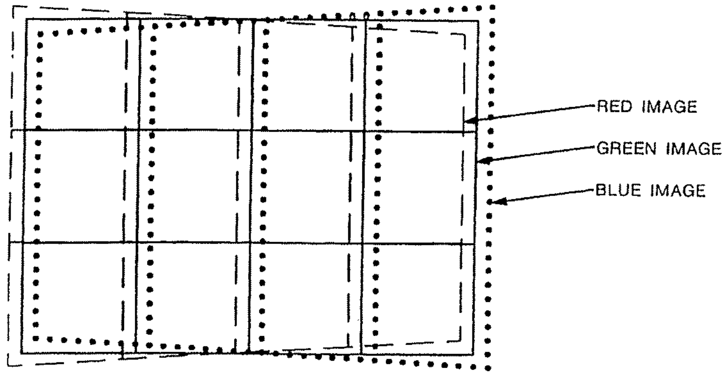


Figure 6.10 Trapezoidal distortion in images caused by off-axis projection.

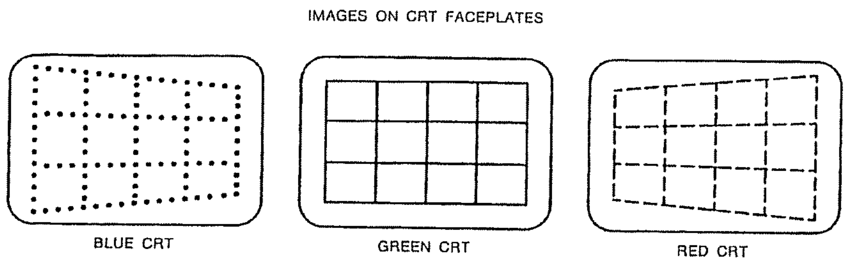


Figure 6.11 Predistorted CRT images for correction of trapezoidal distortion.

coating that reflects blue light incident at 45° and passes all other wavelengths (Fig. 6.14), resulting in all three images exiting the same side of the cube, into the projection optics.

The advantages of the on-axis approach are that trapezoidal correction is not necessary because the images are coaxial before arriving at the screen, only one projection lens is required, and changes in screen size do not require reconvergence of the images.

The disadvantages of an on-axis approach are that the packaging can become large because of the beam combiner and resulting optics and that the design and fabrication of a beam-combining system can be expensive when used with CRTs.

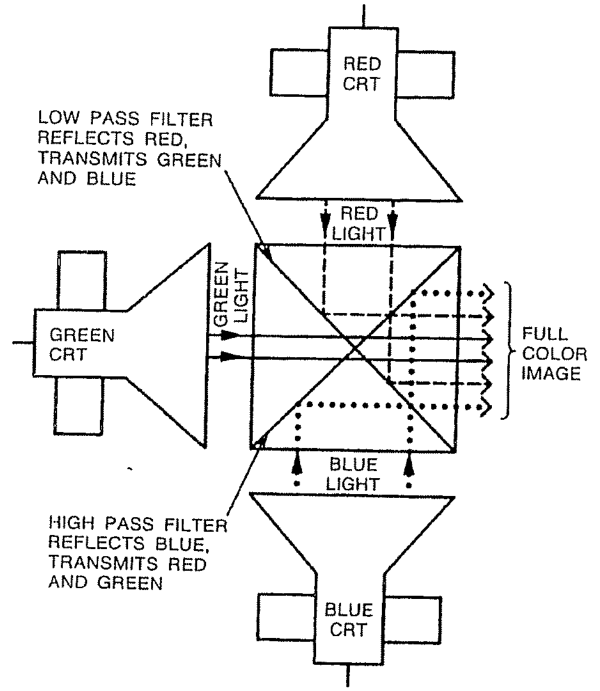


Figure 6.12 Cube beam combiner used in on-axis CRT projection display to combine red, green, and blue images.

Dichroic coatings perform optimally with polarized, collimated, single-wavelength illumination, characteristics that CRTs do not possess. CRTs approximate Lambertian radiators, emitting unpolarized light in all directions, so the cone of light being transmitted through the beam combiner covers a large range of incidence angles and a range of wavelengths. This leaves the design of the projection optics and the beam combiner dichroic coatings in conflict, because it is desirable to collect as much light as possible with the projection optics, requiring a small f number (i.e., a large cone angle), whereas the transmission and color characteristics of the beam combiner work best with a small cone angle. This trade-off usually results in the beam combiner becoming a large, expensive optical component, and so its use in CRT projection displays is limited to higher quality, higher cost systems.

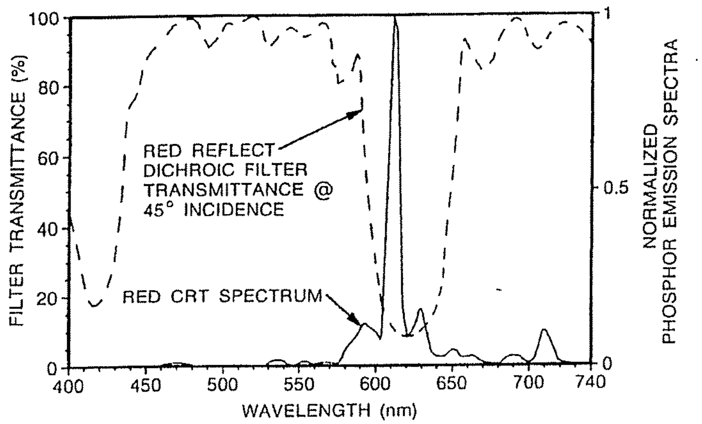


Figure 6.13 Action of red-reflecting dichroic coatings.

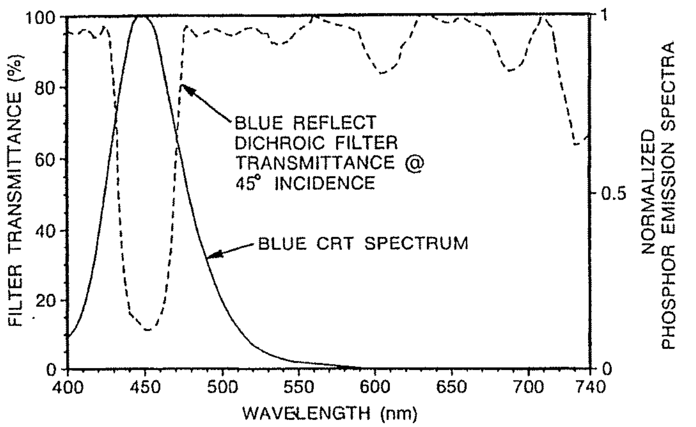


Figure 6.14 Action of blue-reflecting dichroic coating.

6.2.2 Characteristics of CRT Projection Displays

The color gamut of a CRT projection display is determined by the emission spectra of the particular CRT phosphors being used. Typical high-performance projection CRT phosphors are P53 green, P55 blue, and P56 red. These phosphors are specifically designed to withstand the high electron beam currents necessary in a projection CRT. The emission spectrum of the P53, P55, and P56 phosphors is shown in Figure 6.15, and one possible color gamut resulting from the use of these phosphors in Figure 6.16. The color gamut of any particular projection display can be manipulated easily with filters, or different phosphors, so the particular color gamuts shown in this chapter should be considered as examples only.

The screen luminance of a CRT projection display system is given by (Kingslake, 1983)

$$B_s = B_{CRT}TG/4F^2\,(1+m)^2 \qquad (6.3)$$

where B_{CRT} is the luminance of the CRT in foot-lamberts, T is the transmission of the optical system, m is the system magnification, and F is the f number of the optics. In the design of a CRT projection display, these values are adjusted for maximum screen luminance.

One method for maximizing the screen luminance is to maximize B_{CRT}, the luminance of the CRT itself. This is feasible only to the extent that the increase in luminance does not degrade the resolution characteristics of the CRT to be below the system requirements. CRT design improvements aimed at improving

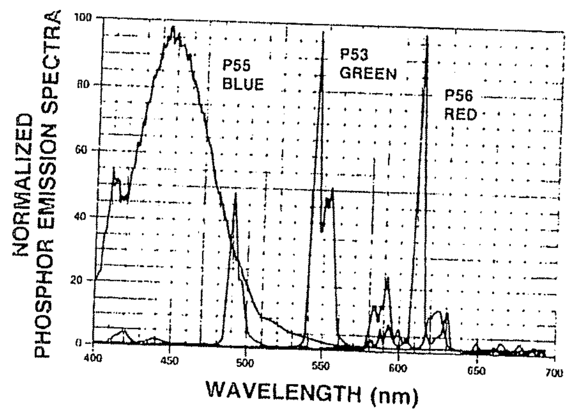


Figure 6.15 Emission spectra of projection CRT phosphors P53, P55, and P56.

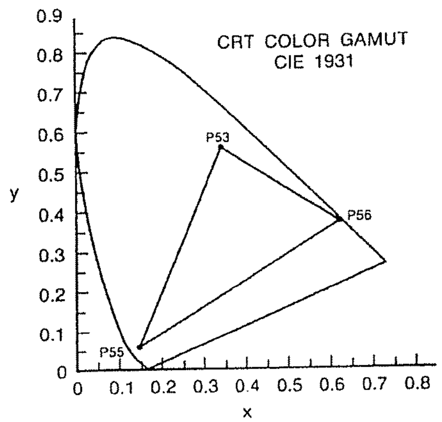


Figure 6.16 Color gamut of CRT projection display using P53, P55, and P56 phosphors.

luminance without compromising resolution include special phosphors and electron guns (Chevalier and Deon, 1985), liquid cooling, interference filters (Vriens et al., 1988), and curved CRT faceplates (Asano et al., 1989; Malang, 1989). Projection CRT phosphors are designed to withstand high beam currents while maintaining adequate lifetimes. Interference filters and curved faceplates both change the luminance distribution so that it is not Lambertian; instead, the luminance is directed more on-axis, and therefore the optics collect more light than they would with a Lambertian source. Liquid cooling between the faceplate and the first optical element not only cools the CRT phosphor, making it more efficient, but also acts as liquid coupling, reducing the losses at glass–air interfaces.

Reducing the magnification and/or the f number of the projection optical system is very helpful in increasing screen luminance, as the luminance varies as the inverse square of these terms. Optical systems have been optimized until refractive systems with f numbers between $f/1.0$ and $f/1.4$ are the most common (Clarke, 1988). The use of aspherical and plastic optics has helped designers create low f number systems that maintain low weight and cost.

The trade-off involved in reducing magnification is that of the physical size of the unit. System magnification is the ratio of the screen size to the image source size. Assuming that a certain screen size is desired, reducing magnification means using larger CRTs, which will improve resolution capability as well as luminance, but at the cost of a larger unit.

Screen gain and optics transmission are the last two parameters that can be

manipulated to increase screen luminance. Optical transmission is maximized by good antireflection coating design and a minimum of glass–air interfaces. Screen gains have increased considerably in the last several years. Screens with a gain of 3–10 are common these days. Increased gain is achieved only by decreasing the available viewing zone, however. Factors involved in the choice of screen gain are discussed in Section 6.6.

Convergence is a major consideration for CRT projection systems. Individual CRTs have their own nonlinearities, which must be corrected. The three images must be overlaid, and they must be corrected until they are all the same shape. Some CRT projection displays have automatic convergence systems, while others have to be manually converged. The type of convergence system used has an effect on how easy the display is to use. Convergence techniques are discussed in more detail in Section 6.7.

There are a wide variety of CRT projection displays available on the marker today. The applications for CRT projection systems are numerous, and the cost and performance of systems span a broad range.

Figure 6.17 shows a consumer CRT projection television with a 40-in. screen diagonal. Like the one shown, most home CRT projection TVs are off-axis systems, which are self-contained so a minimum of convergence and focus adjustments are required by the consumer. These home TVs accept standard NTSC video signals. Home CRT projection TVs are available in a range of sizes from small units with 40-in. diagonal screens, a screen luminance of several hundred foot-lamberts, and weighing about 150 lb, to large units with 70-in. diagonal screens, a screen luminance of about 150 fL, and weighing several hundred pounds.

For these large-screen consumer TVs, CRT projection techniques have provided the proper blend of performance, size, and cost, resulting in steadily increasing popularity. Several companies, including Hitachi (Ando et al., 1989), Toshiba (Murakami et al., 1989), and Mitsubishi (Toide et al., 1991), have developed CRT projection systems for next-generation high-definition television applications.

Cathode-ray tube projection displays are also used to supply large-screen displays for industrial applications. These systems display both video and computer data, with screen sizes ranging from about 60 in. to over 250 in. diagonally. Video/data projectors accept a wide range of input signals, from 525-line video to 1500-line computer-generated information. These CRT projection displays are usually off-axis systems in which the screen is separate from the projector. This results in a projector that can be used with different screens and screen sizes and in both front and rear projection implementations. Figure 6.18 pictures a typical industrial video/data CRT projection display. Typical unit sizes are about 20–25 in. wide, 10–15 in. high, and 30–40 in. long, with weights of about 100–200 lb. The luminance of these units is specified as lumens out of the projector be-

Figure 6.17 A consumer off-axis CRT projection TV with a 40-in. diagonal screen. This system is made by Pioneer.

cause the screen is supplied separately. A large range of luminance output capabilities are available, depending on the performance and cost of a system. The range covers 300–1500 lumens. Video/data CRT projection displays are used for conferences, exhibitions, education, teleconferencing, CAD/CAM, and other audiovisual presentations where the audience is usually large and/or a large screen is necessary.

Another common application of CRT projection displays is in high-performance military and aerospace applications such as flight simulators (El-

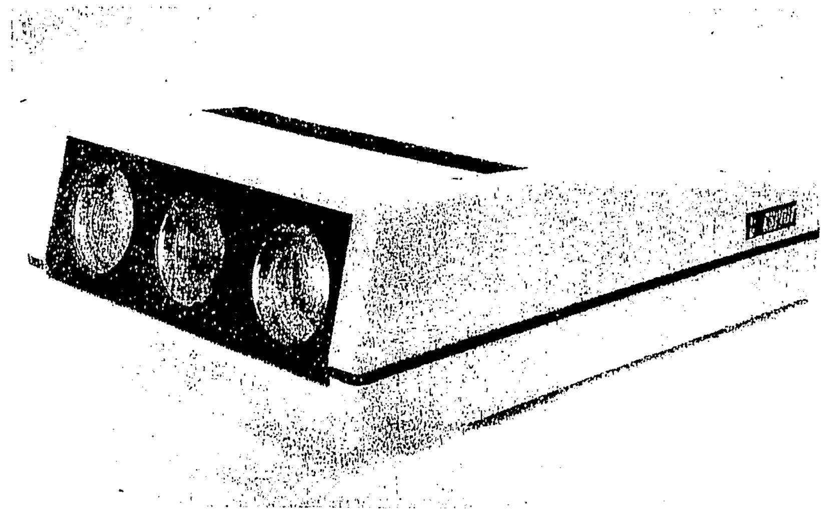


Figure 6.18 Off-axis industrial CRT video/data projection display. This system, by Ampro Corp., uses a reflective CRT. (Photo courtesy of Ampro Corporation, Woburn, MA)

mer, 1982; Holmes, 1987a) and command and control centers. Figure 6.19 shows the internal construction of a very high performance CRT projection display used in instances where the resolution and image quality requirements are very demanding. This is an on-axis system, which gives better performance but costs more than an off-axis system and is usually larger. Most of these high-performance CRT projection displays are built as custom units, so the performance varies with the application, but typical requirements are for resolutions above 1000 lines and light outputs of 800 lumens.

6.2.3 CRT Projection Displays: Summary

CRT projection is a very popular way to achieve large screen sizes and high-resolution images. The technology is well developed, resulting in systems with high performance for a relatively low cost. Applications range from consumer TVs to industrial and military high-performance video and data projectors. As the requirements for these systems expand, however, the shortcomings of CRT

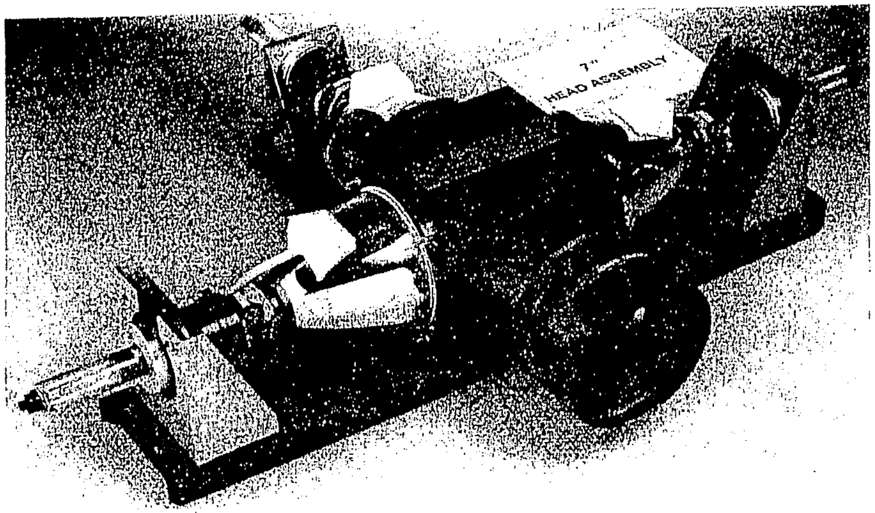


Figure 6.19 Internal construction of a high performance on-axis CRT projection display. (Photo courtesy of TDS Development Corp., Canoga Park, Calif.)

projection become evident: The inverse relationship between luminance and resolution of a CRT forces high-performance systems to use large CRTs, increasing the volume and power consumption of the unit.

6.3 OIL-FILM LIGHT VALVE PROJECTION DISPLAYS

A light valve differs from a CRT in that it does not create light; instead, it controls its transmission. Light valve projection displays consist of a separate light source and image source and the projection optics and screen (Figure 6.20). The light valve is used to modulate the red, green, and blue light from the source into an image.

A very important advantage of a light valve display is that resolution and luminance are no longer interrelated as they are in CRT systems. This allows luminance to be increased without affecting resolution.

The major drawback of light valve systems has historically been their large size, high cost, and high power consumption. They have been able to provide high performance in terms of luminance and resolution, but the size has been large also. This is changing, however, with the recently developed active-matrix

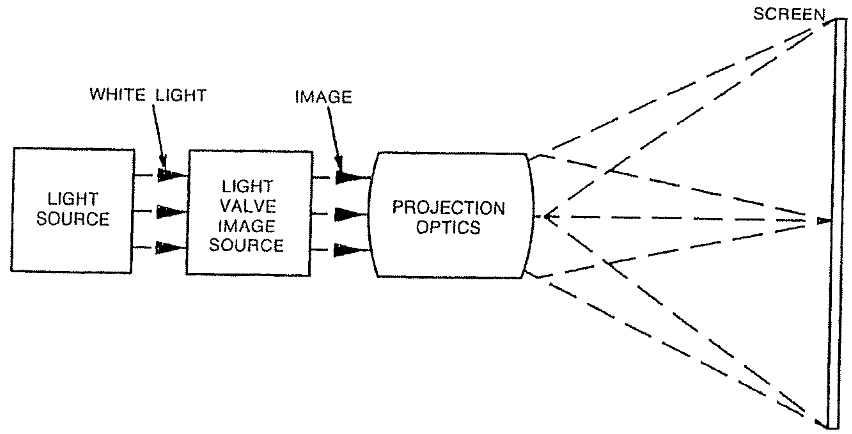


Figure 6.20 Light valve projection display components.

liquid-crystal light valve projection displays, which have the potential to fill a niche for a projection display in a package smaller, less expensive, and lighter than a CRT projection display.

There are many types of light valve display systems. Light valves (LVs) can be made from oil films, deformable mirrors, and liquid or solid crystals. Images are formed by refraction, diffraction, birefringence, or absorption, to name a few examples.

This section and the next review the operating principles of the most common types of light valve projection displays: oil-film light valve (OFLV) projection displays and liquid-crystal light valve (LCLV) projection displays.

6.3.1 Operating Principles of Oil-Film Light Valve Projection Displays

Oil-film light valve (OFLV) projection displays are used when it is necessary to display high-luminance, full-color, real-time video and graphics and the large size and higher cost and power consumption of these systems can be tolerated. Applications of oil-film light valve projection displays include displays for large-audience educational and sporting events, command and control centers, dome simulators, and conference and symposium events.

Oil-film light valve projection displays have been around a long time and represent some of the earliest image projectors. The first OFLV was developed by Fischer in Switzerland around the year 1944 (Baumann, 1953; Johannes, 1989).

A derivative of this system is the Gretag Eidophor projection display, still successfully marketed today. General Electric has developed a projection display using an OFLV, the Talaria, also commonly used today. Both of these displays use a dark-field schlieren system with an oil-film modulator. The advantage of a schlieren optical system is that the system throughput can be very high. There are no absorbers, such as polarizers or dyes, in the system. If a very efficient diffractor is used, almost no light is lost, resulting in a high light throughput system.

In a dark-field schlieren system, a combination of bars and slots is used to block or transmit light, as illustrated in Figure 6.21. The lens images the slots of the object plane onto the bars of the image plane. The input and output spatial filters (bars and slots) form the first set of conjugate surfaces in a schlieren system. The bars are positioned to block the image of the slots, and no light is transmitted.

A transparent deformable film, the oil film, is placed between the bars and slots and a lens to image the film surface onto a projection screen (Fig. 6.22). The deformable film and the projection screen form the second set of conjugate surfaces within the schlieren system. A disturbance or thickness variation in the deformable layer diffracts light from its original path. The light bypasses the bars and is imaged onto the projection screen. Each pixel on the screen corresponds to a pixel on the deformable layer. An unmodulated pixel on the deformable layer

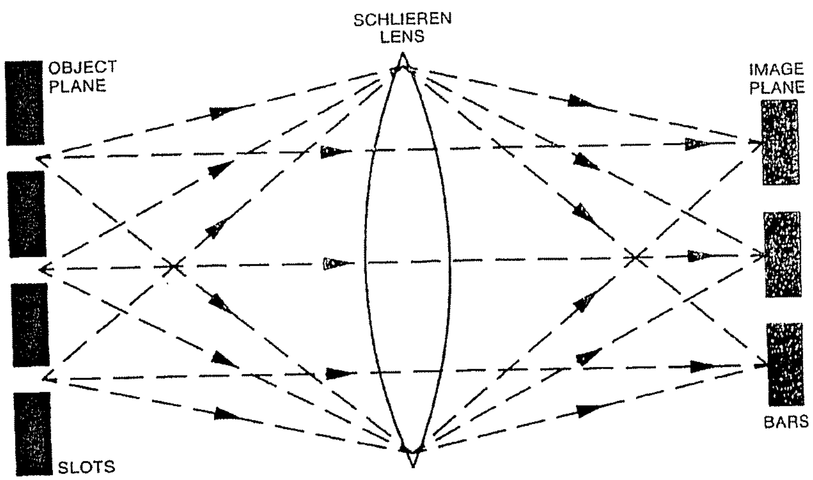


Figure 6.21 Bars and slots of dark-field schlieren system.

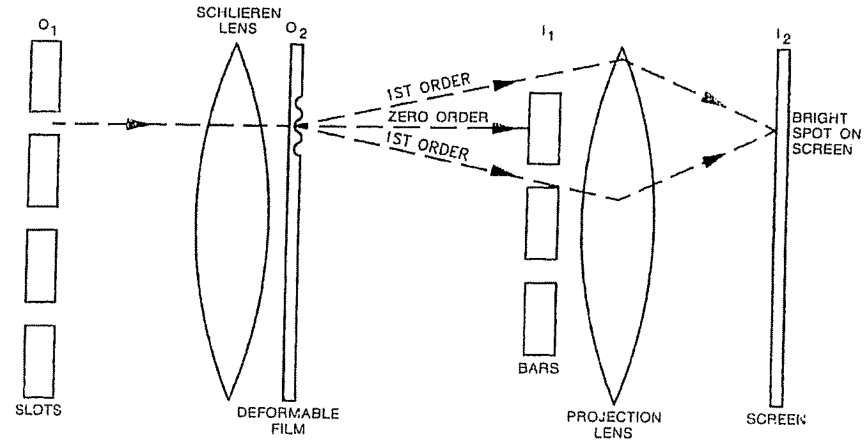


Figure 6.22 Light transmission through a schlieren system using a deformable oil film.

corresponds to a dark pixel on the screen (hence the name dark-field schlieren system), and vice versa.

An electron beam is used to deposit a charge onto the oil film, which provides the modulation. The electron beam moves over the oil film in a raster format. The velocity of the electron beam determines the amount of charge deposited, which determines the depth of the sinusoidal diffraction grating formed in the oil film. When no charge is deposited, the oil is not deformed, and adjacent oil-film raster lines overlap, creating a smooth oil-film surface. There is no diffraction, and no light transmission occurs. When charge is deposited, sinusoidal raster grooves are formed in the oil film, creating the phase grating. Diffraction angle and amount of light diffracted are determined by the basic diffraction equations (Hutley, 1982). Maximum grating depth results in maximum pixel intensity. Gray scale is provided by levels of charge between minimum and maximum. Both the Gretag Eidophor and the GE Talaria use this basic system, with some color implementation differences.

The Gretag Eidophor uses three schlieren light valves, one for each color, with a high-intensity light source providing white light. The white light is separated into its constituent red, green, and blue components with dichroic filters, in a process that is the reverse of the beam combining used in the CRT on-axis projection display. The separate red, green, and blue light is then sent to the corresponding light valves. The basic configuration of an Eidophor light valve is

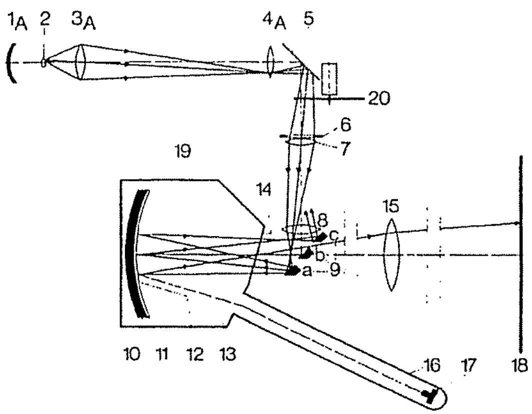
shown in Figure 6.23. The oil-film control layer resides on a spherical mirror. Light reflects off the mirror, and the set of bars act as both bars and slots.

The Talaria OFLV projector takes advantage of the separation of colors that occurs in diffraction to provide all three color images with a single light valve (Glenn, 1958; Good, 1968). By using the angle of diffraction dependence on wavelength (Fig. 6.24) and carefully controlling the spacing of slots and bars, a single light valve unit can provide full color control.

The GE OFLV uses two sets of slots and bars, one to control green light and another to control red and blue light combined (magenta light). The slots consist of two sets of dichroic filter slots overlaid one on top of another (Fig. 6.25). The vertical slots, bars, and control layer pattern are used to modulate the red and blue light. The wavelengths are far enough apart that both can be controlled with the same slots/bars, and the two diffraction frequencies are overlaid at the control layer. Modulation of the green light by the magenta grating does not affect it because diffraction occurs along the green bars, and vice versa.

Green light modulation, occurring orthogonal to the red and blue, takes place just as in a monochrome system. Color selection in the GE light valve is illustrated in Figure 6.26.

The GE single-electron-beam, single-control-layer, full-color light valve (Fig. 6.27) was introduced in 1968. It has advantages of size and registration because it uses only one light valve.



1A AUXILIARY SPHERICAL MIRROR
2 EXTREME POINT OF THE LIGHT SOURCE
3A CONDENSER LENS
4A CORRECTION LENS
5 COLD MIRROR
6 PICTURE WINDOW
7 CONVERGING LENS
8 FIELD LENS
9a,b,c BAR SYSTEM
10 SPHERICAL MIRROR
11 CONTROL LAYER
12 PERTURBATION IN THE OIL LAYER
13 ELECTRON BEAM
14 CLOSING WINDOW
15 OBJECTIVE LENS
16 ELECTRON GUN
17 CATHODE
18 SCREEN
19 VACUUM CHAMBER
20 COLOR WHEEL

Figure 6.23 Gretag Eidophor oil-film light valve configuration. (Courtesy SAIC, McLean, Va.)

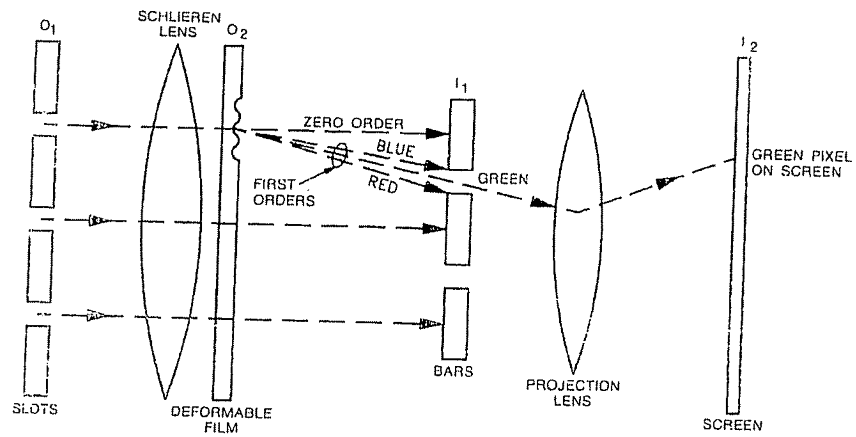


Figure 6.24 Color separation in oil-film light valve by diffraction.

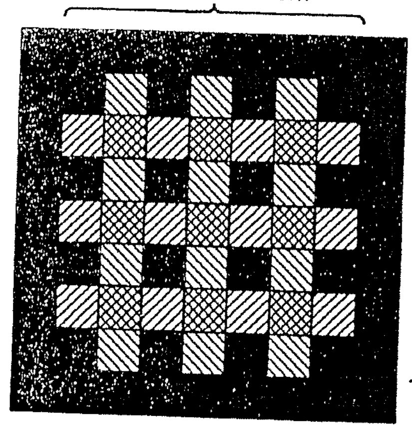


Figure 6.25 Green and magenta color filter slots are superimposed on one another in GE schlieren light valve.

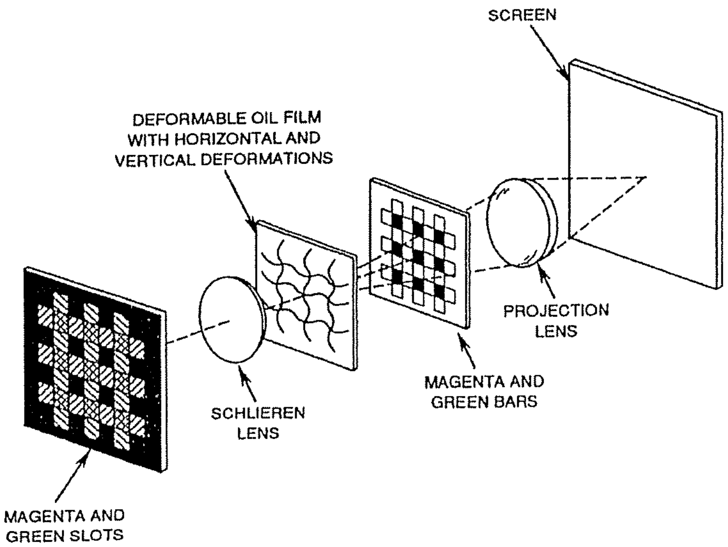


Figure 6.26 Green and magenta color selection occurs orthogonally in GE schlieren light valve.

6.3.2 Characteristics of Oil-Film Light Valve Projection Displays

Both the Talaria and Eidophor systems provide full color, although their respective color gamuts are determined differently. In the GE system, color is determined by the dichroic filter slots and the filtering action of the magenta slots on the red and blue colors individually. The University of Dayton (Howard, 1989) has characterized the color performance of the Talaria display. In the Gretag display, color is determined by the dichroic filters used to divide the white light into red, green, and blue components.

Oil-film LV projection displays typically operate at 60 Hz refresh rates and are available in both monochrome and full-color systems. There are a range of systems available, with varying capabilities. Lumens out of the systems run from 2000 to 8000 white lumens, and addressabilities of over 1000 scan lines are available in both types. These systems are quite large and heavy, but they can provide very large bright video images. Figure 6.28 is a picture of the Gretag Eidophor projector, and Figure 6.29 shows the GE Talaria projector.

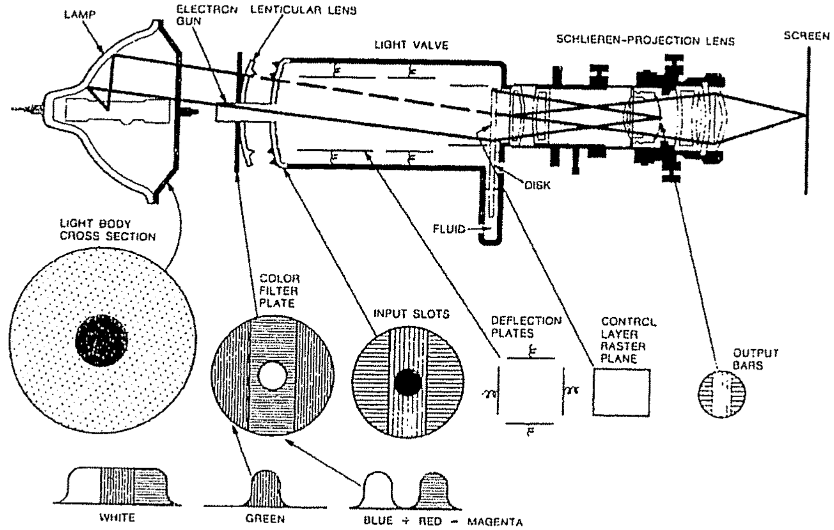


Figure 6.27 GE Talaria full-color light valve diagram. [From Good (1976), courtesy of the author.]

The configuration of the GE system has size advantages because it contains only one light valve, whereas the Eidophor has three. It also does not need to be converged like a separate light valve system does. The use of a single light valve does tend to limit luminance capability, however. General Electric has also introduced a two-light-valve system (True, 1987) in which one light valve modulates green and the other modulates red and blue. This has increased the total light output capability of the Talaria.

6.3.3 Oil-Film Light Valve Projection Displays: Summary

An OFLV projection display uses a schlieren optical system with an oil-film modulator to create an image. One advantage of these displays is their high light output, which results from a high-output lamp and an efficient schlieren optical system. Another advantage is that the resolution and luminance of the display are not related as they are with CRTs. Consequently, OFLV projection displays are capable of projecting images with both high luminance and high resolution. Their large size and relatively high cost limit their use to applications where this high performance is necessary and affordable. Oil-film LV projection displays